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ANTHROPOMETRIC CONSIDERATIONS FOR BIOKINEMATIC RESEARCH

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ABSTRACT

Human engineers seeking to adapt static measurement data to the problems of biomechanics encounter several major stumbling blocks. At present there are no methods available for providing statistical anthropometric data directly suitable for analysis of the dynamic human system. New anthropometric techniques must be developed which define the body within a three-dimensional frame of reference while providing information on the size and shape of the internal skeleton, external surfaces, linkage system, and spatial relationships among all body segments.

This paper suggests some approaches for obtaining measurements of the body in three-dimensional space, viewing the body as a unified system and, above all, standardizing measurements so that data can be reliably analyzed. Specifically, it proposes a set of landmarks related to coordinate systems for the head, thorax, and pelvis and suggests a method for utilizing current techniques and data in biokinematic studies.

Preface

The following paper was prepared as a result of three recent events. The first event was my submission of a proposal to the Air Force Office of Scientific Research to conduct basic research in the development of a new approach in anthropometry. The objective of this program is indicated in the present paper. Second, I was asked to join the Ad-Hoc Committee chaired by Dr. D. J. Thomas. My first task for the committee meeting in 1975 was to "recommend definitions for anthropometric landmarks for establishing coordinate systems in the head, thorax, and pelvis." In addition, I was asked to "prepare a discussion of the anthropometric considerations implicit in defining a coordinate system." The third event occurred relative to a research program at HSRI. I had prepared a list of anthropometric dimensions to be used in a Whole-Body Response Program under the sponsorship of General Motors. John Melvin, Director of the Project, asked me to present this list at the Committee meeting of 1975. It is included as an appendix in the present paper. Thus, with all three events occuring within months of each other, I felt that it was time to examine formally the field of anthropometry as it pertains to biokinematic research.

This paper has been read and critiqued by the following physical anthropologists:

Mr. Charles E. Clauser, WPAFB
Mr. Kenneth W. Kennedy, WPAFB
Dr. John T. McConville, Webb Assoc.
Dr. Richard G. Snyder, HSRI
Mr. Joseph W. Young, CAMI

Their comments have in general, been incorporated into the present paper. I am, however, responsible for the final product for among each of us there are differences in the specific approach to the problem. However, I believe that I can speak for each of us when I state that traditional anthropometry has served a useful function. However, it is now time to develop a new methodology and technique suitable for describing the size and shape of the human body in three-dimensional space.

The present paper does not propose solutions as much as it attempts to define the problem as we, as Physical Anthropologists, percieve it. Thus, it is important to establish a dialogue between engineers and human biologists interested in this area in the hopes that forthcoming work will be fruitful for both disciplines.

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I. STATEMENT OF THE PROBLEM

Classical measurements and techniques in traditional anthropometry were originally devised to study human variation with respect to the origin and evolution of man. Human engineers and applied anthropologists have adapted traditional techniques for application to modern biomechanical research problems. Many of these adaptations provide useful size and shape information, but they still retain the primary limitation of being static measurements which are position-dependent. Furthermore, they are linear landmark-to-landmark dimensions which must be interpreted and used with caution. Thus, the problem for researchers using traditional anthropometric techniques is to utilize this static information in a manner which does not introduce errors into their dynamic data.

Traditional anthropometry provides precise and accurate body information insofar as the anthropometrist locates specific landmarks, positions his subject in a standardized position, and measures within the "anthropometric three-dimensional axis system." Landmarks on the body present the experienced anthropometrist with a difficult problem, since there are no points on the body but only areas. This is particularly true when somatometric dimensions are taken on a living body or on a cadaver. In osteometry, on the other hand, skeletal landmarks can be much more precisely identified and measured. When soft tissue overlies the body landmark, the anthropometrist must first find the landmark by palpation or radiography, and then project that landmark in a defined direction to a point or level on the surface of the skin. This paper will discuss the problem of landmarks with respect to co-ordinate systems for the head, thorax, and pelvis.

As pointed out by Robbins and Reynolds (1974), "The techniques used for presentation of anthropometric data (e.g., measurements of heights, lengths, spans, circumferences, etc.) are insufficient for locating a body in space in the sense of classical mechanics (p.6)." They pointed out that specific frames of reference are necessary. In summary, one can conclude from traditional techniques that anthropometric data are measured within an anatomical axis system which has no common point of origin. Thus, measurements are made parallel and perpendicular to the frontal (YZ), transverse (XY), and sagittal (XZ) planes, but the coordinate origin of these intersecting planes is undefined. Therefore, this paper also presents the means by which this undefined axis system may be better utilized in biokinematic studies.

Since traditional anthropometry describes static dimensions of the body, a standardized position is necessary for comparable results within and among studies. Several positions have traditionally been used in anthropometric surveys. For living subjects, standing and sitting postures are assumed by the subject for measurements that relate best to those positions, either for reasons of function or convenience. Cadavers, however, require special attention. Some of these problems have been reviewed by Clauser, McConville, and Young (1969). In general, cadavers are best measured in a supine position, but the orientation of the body relative to the measurement surfaces is critical.

In examining these three critical areas in traditional anthropometry, it has become evident that a new approach is required. Basic research in this area has been proposed by the present author and is expected to begin shortly. This new approach must define the body within frames of reference while providing information on the size and shape of the internal skeleton external surface, linkage system, and spatial relationships among all body segments. It must, above all, provide statistical anthropometric data suitable for analysis of the dynamic human system. At present, however, these data and techniques are not available.

Therefore, the following discussion will provide some guidelines which can assist in standardizing anthropometric data currently being collected in biokinematic research programs.

II. SELECTION OF LANDMARKS FOR AN AXIS SYSTEM

Two aspects of anthropometry must be considered in defining anatomical coordinate axes systems. First the landmarks chosen to define the anatomical axis system must be reliably and reproducibly located and must be at a maximum distance from one another. Second, in order to evaluate the biokinematic results from different subjects and samples, anthropometric data describing the size and shape of the body as well as the linear relationships among the coordinate axes systems are necessary. Thus, anthropometry is implicit in the selection of landmarks for axis system development and in the interpretation of data based on these anatomical axes systems.

As has been demonstrated previously, landmarks, as points on a body surface, are difficult to obtain. Traditional anthropometry has defined most landmarks as a level to which a measurement is made rather than a point. As a result, when examining anthropometric survey reports and other sources which define anthropometric landmarks, the definition of the landmark is made for a plane passing through the bony structure. For example, acromion is defined as the most superior edge of the lateral projection of the acromion process of the scapula. Acromion is then located as a measured distance above a supporting surface, floor, or seat, and assuming bilateral symmetry, a distance to the right and left of the midsagital plane from the dimension of biacromial breadth. These measurements have not needed an X-axis, or anterior-posterior location of acromion, since the two measurements taken at this level are not affected by its location along the X-axis. With the three-dimensional requirements of biokinematics research, each landmark must be defined in three dimensions. New landmarks and definitions are at present not available, since research in this area has just begun. Any attempt to define traditional landmarks in three dimensions may be presumptive and possibly misleading, since there is no assurance that many of these landmarks can be defined as a point in three dimensions. It may be necessary to develop an entirely new category of anthropometric landmarks which are suitable for three-dimensional location and definition.

III. PROPOSED INTERIM LANDMARKS FOR COORDINATE SYSTEMS IN THE HEAD, THORAX, AND PELVIS

Traditional anthropometric landmarks are based on (1) anatomical features of the skeleton, and (2) external body surface contours. Neither of these is necessarily expressed as a point. Landmarks are defined as an area or volume which ranges in size and difficulty of location from nasion (on the fronto-nasal suture in the mid-sagittal plane) to acromion or trochanterion (at the most superior projection of the Greater Trochanter of the femur in the erect standing position). Nasion represents a small area approximately 1 mm^2 on the skull which can be located irrespective of skull position. This landmark is located precisely only in the absence of soft tissue; otherwise, anthropometrists often use another landmark on the skin surface which is close but does not represent nasion, namely, sellion (the deepest point in the Nasal Root Depression in the Mid-Sagittal Plane). The other two landmarks--acromion and trochanterion--are defined relative to an anatomical position and a plane through the bony structure in the prescribed position. Furthermore, when the body changes position, the definition must also be changed in order to locate approximately the same landmark. Both of these landmarks are more appropriately used as a level than a point. Thus, the precision with which landmarks can be located covers a wide range which must be acknowledged and dealt with in anthropometry.

In biokinematic anthropometry, landmarks must be located as skeletal features with the body in a well-defined position. For all of the landmark locations, the body should rest initially in a supine anatomical position so that the following definitions of direction will remain constant.

Anterior - towards the front (+X)

Posterior - towards the back (-X)

Lateral - towards the side: Left (+Y)
Right (-Y)

Medial - towards the middle : Left (-Y)
Right (+Y)

Superior - towards the head (+Z)

Inferior - towards the feet (-Z)

Using this anatomical terminology with its corresponding right-handed axis system notation, the landmarks useful for coordinate systems of the head, thorax, and pelvis will be defined.

Furthermore, it is recommended that right-handed, orthogonal axes systems be established using a minimum of three landmarks, located either by palpation or radiography, to establish a plane of orientation. These landmarks should be suitable for anthropometric description on both living and cadaveric subjects. Furthermore, these landmarks should be selected so that they form a plane approximately parallel to one of the cardinal anatomical planes of the body.

A. Head Axis System

The following landmarks can be considered stable reference points for the head axis system:

1) Nasion - at the point of intersection of the frontal and two nasal bones in the mid-sagittal plane. The point is found on the anterior surface of the face approximately mid-way between the two medial edges of the bony eye sockets. It is difficult to locate with complete accuracy on the living but can be closely approximated.

2) Infraorbitale - the most inferior point on the inferior-anterior margin of the bony eye orbit. This point is found on both eye orbits and it is recommended that the location on the left orbit be used in defining the Frankfort Plane.

3) Porion - the most superior point on the superior-lateral margin of the external auditory meatus (bony ear hole). This point is found on both right and left ear holes and it is recommended that both points be used in defining the Frankfort Plane.

There are numerous planes available for use on the head (Krogman, 1951). With the three landmarks presented here (5 locations), there are several options, among which is the Frankfort Plane. It is recommended herein that the Frankfort Plane as defined by Right and Left Porions and Left Infraorbitale be used as the basis of the head coordinate system.

For the head, the axis system can be formed relative to the Frankfort Plane which in the anthropometric measurement position is parallel to the transferse (XY) plane. The Frankfort Plane (XY) is established by left Infraorbitale and right and left Porions. The YZ plane will be perpendicular to the XY plane, passing through the right and left Porions. The XZ plane will be constructed as a normal to the XY and YZ planes, passing through Nasion in the mid-sagittal plane. Thus, the point of origin will be at the mid-point of the Biporion axis, with the +X-axis passing anteriorly at the intersection of the XZ and XY planes, the +Y-axis passing laterally at the intersection of the XY and XZ planes, and the +Z-axis passing superiorly at the intersection of the XZ and YZ planes.

B. Thorax Axis System

As discussed in the last Ad-Hoc Committee Report, "Guidelines for the Comparison of Human and Human Analogue Biomechanical Data" (1974), the thorax presents two unique problems with respect to biokinematic tests. First, the thorax may be considered a rigid body. Second, the thorax may be considered a non-rigid, deformable, plastic body which can be treated as a series of twelve vertebrae with associated anatomical masses moving in space. When both extremes are possible as well as all developments in between the two extremes, there are no anthropometric landmarks currently used on the thorax which are suitable for accurately defining a three-dimensional coordinate axis system.

The T1 axis system developed by Ewing and Thomas (1972) suffers from attempting to define points on small areas separated by small linear distances. Thus the locations of the points in three dimensions are not reliable. Furthermore, there is very little anthropometric data using the spinous process of the first thoracic vertebrae as a dimensional landmark. Therefore, the anthropometric location of T1 relative to other landmarks used in coordinate axis systems is unknown. The same comments can be made with respect to all axis systems based on a single vertebra.

At the other extreme, the axis system as proposed by Robbins and Reynolds (1974) which describes the thorax with a single co-ordinate system also has limitations. A slightly modified version of that previously mentioned axis system can be constructed using Suprasternale and the spinous processes of T1 and T12. These three landmarks have the advantage of being widely separated in space, and being relatively easy to locate either by palpation or radiography. However, only Suprasternale has been used in anthropometric surveys as a body landmark, thereby defining its relationship to either of the landmarks used in coordinate systems.

The following landmarks should be considered candidates for the thorax axis system:

1) Spinous Process of T1 - the posterior-superior point in the mid-line of the spinous process of the first thoracic vertebra.

2) Spinous Process of T12 - the posterior-superior point in the mid-line of the spinous process of the twelfth thoracic vertebra.

3) Suprasternale - the lowest point in the mid-sagittal plane on the anterior-superior margin of the manubrium. This point lies in the sternal notch and is found by palpation.

For the thorax, the axis system will be formed relative to the mid-sagittal (XZ) plane defined by suprasternale and the most posterior-superior points on the spinous processes of the T1 and T12 vertebrae. The YZ plane will be formed as a perpendicular to the mid-sagittal plane passing through the T1 and T12 landmarks. The XY plane will be constructed as a normal to the XZ and YZ planes passing through the T1 landmark. Thus, the point of origin will be at the T1 landmark with the +X-axis passing anteriorly along the intersection of the XY and YZ planes; the +Y-axis will pass laterally along the intersection of the SY and YZ planes; and the +Z-axis will pass superiorly along the intersection of the XZ and YZ planes.

C. Pelvis Axis System Landmarks

The pelvis can be treated as a rigid body with anatomical landmarks that maintain constant spatial relationships. The pelvis is similar to the head in that there are several planes that can be constructed. Unlike the head, however, some of these planes could conceivably be more appropriate than others in describing the dynamic characteristics of the body. For the present, a plane which has been used (Dempster, 1955) and is constructed using palpable landmarks will be recommended.

The following landmarks are recommended as potential candidates for use in constructing an axis system for the pelvis:

1) Anterior Superior Iliac Spine - a point on the ilium of the pelvis located as the superior spine of the anteriorly descending iliac crest. The point on both right and left inominate bones can be identified by the superior attachment of the inguinal ligament on the anterior-lateral surface of the abdomen.

2) Symphysion - a point approximately in the mid-sagittal plane which lies on the superior-anterior margin of the pubic symphysis. This point can be located by palpation on the medial-anterior surface of the lower abdomen.

3) Posterior Superior Iliac Spine - a point on the pelvic ilium located as the superior spine of the posteriorly descending iliac crest. The point on both right and left inominate bones can be identified as a projection on the medial-posterior surface of the back at the approximate level of the 2nd sacral vertebra.

The right and left Anterior Superior Iliac Spines are palpable and there are anthropometric data in the literature describing their location relative to other body landmarks. The other three landmarks--Symphysion and the right and left Posterior Superior Iliac Spines--are difficult to palpate. A limited amount of anthropometric data is available on the location of Symphysion, but there are none on either of the Posterior Superior Iliac Spines.

For the pelvis, it is recommended that a frontal plane (YZ) be established using Symphysion and the right and left Anterior Superior Iliac Spines. The XY plane will be constructed as a normal to the XY and YZ planes passing through Symphysion. The point of origin will be the mid-point of the Bispinous diameter, with the +X-axis passing anteriorly along the intersection of the XY and YZ planes, and the +Z-axis passing superiorly along the intersection of the XZ and YZ planes.

IV. THE BODY AS A SYSTEM: THE NEED FOR STANDARDIZATION OF MEASUREMENTS

Past efforts at studying the body as a collection of disparate segments rather than a single system have introduced errors when the data were compiled into composite descriptions of the whole body. Many of these errors accumulate rapidly and significantly when data collected on different subjects and by different investigators are compiled. Variation in the samples is uncontrollable, and very little information is available to discern possible sources of measurement bias between the different investigators, particularly when these data were collected on human subjects--living or cadaver. Anthropometry, such as that reported by Ewing and Thomas (1972), can be used to evaluate the significance of biokinematic differences among different samples if the other samples report some of the same anthropometric information. Even if the measurements are the same but the definitions are different, corrections can sometimes be made to account for these small differences. With these types of data, an initial evaluation of comparability can be made with regard to the size and shape of the samples from which the data were collected.

Ideally, there should be a "core list" that should include measurements describing the anthropometric location of the landmarks used in the head, thorax, and pelvic anatomical axes systems. The measurements that describe the anthropometric location of the anatomic axes systems landmarks are particularly important, since they are part of the basis for evaluating the human kinematic system. That is, different segments of the body may be studied separately and integrated into whole-body data only if there are comparable data that adequately describe the samples. Major emphasis should be placed upon obtaining these data in each of the separate studies. These data should anthropometrically describe the location of the landmarks discussed previously or others if these are not suitable. Furthermore, they should include a minimal list of dimensions that describe the size of the body. If the protocol permits, these latter measurements should describe the whole body as well as each of the principal segments of the body--head, torso, upper arm, forearm, hand, thigh, calf, and foot. These measurements should be chosen to reflect the best anthropometric estimate of mass distribution of the body.

The following ten measurements are recommended as the minimal list for landmark anthropometry:

1) Tragion Height
2) Tragion Depth
3) Bitragion Breadth
4) Suprasternale Height
5) Suprasternale Depth
6) Right Anterior Superior Iliac Spine Height
7) Left Anterior Superior Iliac Spine Height
8) Right Anterior Superior Iliac Spine Depth

9) Left Anterior Superior Iliac Spine Depth
10) Bispinous Breadth

These measurements are defined in the appendix, where a more complete list of measurements is presented for cadaver anthropometry. These measurements do not constitute the "core" list but should be included either as anthropometric dimensions or three-dimensional coordinate locations of the landmarks.

The list of measurements and landmark definitions found in the appendix represent the type of anthropometric dimensions used in the past to describe or estimate linkage and mass distribution properties in man. These dimensions provide the user with spatially unrelated chord lengths. At their best, these anthropometric dimensions are expressed as a height from the floor, but the spatial relationships among the four measurements (height, breadth, depth and circumference) are basically unknown. Thus, not only is it important to treat the human body as a system, but it is also important to have a measurement methodology which is spatially composed.

For example, the axis system described for the pelvis is essential in order to treat the body as a system. One view of the human system can substantially describe the movement of the body, whether voluntary or involuntary, as motion around the pelvis. One significant rationale for this approach, without even considering postural and kinematic sequences, is that the center of mass, when considered as an instantaneous center, most frequently lies closest to the pelvis.

One can conclude that the anthropometric considerations implicit in defining co-ordinate systems are the anthropometric description and location of these axes systems relative to each other, the body linkage system, and the mass distribution of the body. The present author is attempting to deal with these problems and plans to initiate research in this area under the Air Force Office of Scientific Research in the forthcoming year.

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APPENDIX

Traditional Anthropometry for Cadavers

The following list of measurement and landmark definitions was selected to provide anthropometric data needed for mathematical models of the human linkage system and mass distribution. These measurements have been designed for cadaver anthropometry with the cadaver in a supine position on its back. The cadaver's head must be positioned in the Frankfort Plane with a measurement board (approximately 2' x 2') tangent to vertex. perpendicular to the surface on which the cadaver is resting, and parallel to the Frankfort Plane. The cadaver is aligned so that the mid-sagittal plane is perpendicular to the measurement board. The cadaver is oriented within an axis system which, if symmetry is assumed, will provide three-dimensional coordinate data for some landmark locations relative to a point of origin located at the intersection of the mid-sagittal plane, head measurement board, and resting surface of the cadaver. Thus, heights from the head measurement board will provide Z-coordinates and symmetry will be assumed for the Y-coordinates, using Symphysion and Suprasternale to define the mid-sagittal axis. Where the full complement of three measurements is not present in the following list, the missing measurement is easily added. Thus, this list will provide the researcher with data suitable for use in describing the size, shape, linkage, and estimated mass distribution of each of his subjects.

Some initial requirements for accurate measurements should be reviewed. The most important requirement is to take the measurements in a sequence that does not move the body once it is positioned within the measurement axis system. The sequence given in the following list takes all axial measurements first and all circumferential measurements last. Another aspect of this requirement which also addresses a major area of anthropometric interest concerns how those data on the torso are spatially related to the spinal column. It will be observed that all torso measurements are made with the cadaver resting on his back. If possible, following all anthropometry, radiographs should be taken to locate the anterior torso landmarks relative to the spinous processes of the vertebrae. If an x-ray machine is unavailable, these locations are practically unobtainable. Attempts to rest the body on the anterior surface and measure the height of the spinous process of T1 and T12, for example, have proven unreliable, since the position of the body is significantly different from where the remainder of the measurements are made. Thus, the solution is not presently available and research and discussion is needed on this subject.

The second requirement concerns measurement technique. The instruments must always be carefully aligned in the axis system so that the beam is parallel to the measurement planes. In essence, all anthropometrists must be able to refer to the same model of the body--i.e., a musculoskeletal system within anatomical planes. During measuring procedures, this model must be duplicated by both the anthropometrist with his instruments and the position of the subject. The accuracy and reliability of all anthropometric data is dependent upon consistency within this anthropometric model. Thus, all measurements must be made within the confines of this anthropometric model and its associated assumptions.

The following list of measurements and definitions contains a model for cadaver anthropometry. The list will need revision, and differences of opinion regarding specific measurements will occur; but out of this scientific dialogue will emerge a model for cadaver anthropometry that will remain consistent for all studies.

A. List of Measurements

1.	Weight		______
2.	Stature		______
3.	Trochanterion Hgt.		______
4.	Symphysion Ht.		______
5.	Anterior Superior Iliac Spine Hgt.	Rt.	______
		Lt.	______
6.	Iliocristale Hgt.	Rt.	______
		Lt.	______
7.	Substernale Hgt.		______
8.	Mid-Chest Hgt.		______
9.	Suprasternale Hgt.		______
10.	Acromion Hgt.	Rt.	______
		Lt.	______
11.	Menton Hgt.		______
12.	Mastoid Hgt.	Rt.	______
		Lt.	______
13.	Tragion Hgt.	Rt.	______
		Lt.	______
14.	Tragion Depth	Rt.	______
		Lt.	______
15.	Suprasternale Depth		______
16.	Mid-Chest Depth		______
17.	Substernale Depth		______
18.	Anterior Superior Iliac Spine Depth	Rt.	______
		Lt.	______

19. Symphysion Depth ______________

20. Trochanterion Depth Rt. ______________

Lt. ______________

21. Suprasternale-Acromion Distance Rt. ______________

Lt. ______________

22. Biacromial Breadth ______________

23. Bideltoid Breadth ______________

24. Mid-Chest Breadth ______________

25. Chest Breadth at Substernale ______________

26. Hip Breadth at Iliocristale ______________

27. Bispinous Diameter ______________

28. ASIS to Symphysion Distance Rt. ______________

Lt. ______________

29. Bitrochanteric Breadth ______________

30. Acromion-Radiale Length ______________

31. Ball of Humerus-Radiale Length ______________

32. Radiale-Stylion Length ______________

33. Hand Length ______________

34. Hand Breadth ______________

35. Hand Depth ______________

36. Wrist Breadth ______________

37. Forearm Depth ______________

38. Upper Arm Depth ______________

39. Trochanterion-Fibulare Length ______________

40. Fibulare-Lateral Malleolus Length ______________

41. Tibiale-Sphyrion Length ______________

42. Tibiale-Heel of Foot Length ______________

43. Foot Length ____________
44. Foot Breadth ____________
45. Minimum Ankle Breadth ____________
46. Calf Depth ____________
47. Upper Thigh Breadth ____________
48. Head Breadth ____________
49. Head Length ____________
50. Bitragion Breadth ____________
51. Bigonial Breadth ____________
52. Menton Diagonal Length ____________
53. Mastoid-Crinion Length ____________
54. Head Circumference ____________
55. Mid-Sagittal Arc Length ____________
56. Bitragion-Coronal Arc Length ____________
57. Mid-Neck Circumference ____________
58. Chest Circumference at Mid-Chest ____________
59. Chest Circumference at Substernale ____________
60. Hip Circumference at Iliocristale ____________
61. Buttocks Circumference at Trochanterion ____________
62. Upper Arm Circumference (Mid-Biceps) ____________
63. Maximum Forearm Circumference ____________
64. Minimum Wrist Circumference ____________
65. Upper Thigh Circumference ____________
66. Maximum Calf Circumference ____________
67. Minimum Ankle Circumference ____________

B. List of Measurement Definitions

1. Weight: Record the nude weight of the cadaver to the nearest pound at time of measurement.

2. Stature: Lay the cadaver on the measuring table with head in the Frankfort Plane against a board tangent to Vertex and parallel to the Frankfort Plane. Measure with an anthropometer the perpendicular distance from the headboard to the most distal point on the heels of the feet and average for total stature. The measurement should be parallel to the long axis of the body.

3. Trochanterion Height: Measure with an anthropometer the perpendicular distance from the headboard to right and left Trochanterion surface landmarks. The measurement should be parallel to the long axis of the body.

4. Symphysion Height: Measure with an anthropometer the perpendicular distance from the headboard to the Symphysion landmark. The measurement should be parallel to the long axis of the body.

5. Anterior Superior Iliac Spine Height: Measure the perpendicular distance from the headboard to the right and left Anterior Superior Iliac Spines. The measurement should be parallel to the long axis of the body.

6. Iliocristale Height: Measure the perpendicular distance from the headboard to right and left Iliocristale landmarks. The measurement should be parallel to the long axis of the body.

7. Substernale Height: Measure the perpendicular distance from the headboard to Substernale. The measurement should be parallel to the long axis of the body.

8. Mid-Chest Height: Measure the perpendicular distance with an anthropometer from the headboard to the point on the anterior surface of the chest mid-way between Suprasternale and Substernale. The measurement should be parallel to the long axis of the body.

9. Suprasternale Height: Measure the perpendicular distance with an anthropometer from the headboard to Suprasternale. The measurement should be parallel to the long axis of the body.

10. Acromion Height: Measure the perpendicular distance with an anthropometer from the headboard to right and left Acromion. The measurement should be parallel to the long axis of the body.

11. Menton Height: With the head in the Frankfort Plane against a board tangential to Vertex and parallel to the Frankfort Plane, measure the perpendicular distance from the headboard to Menton.

12. Mastoid Height: With the head in the Frankfort Plane against a board tangential to Vertex and parallel to the Frankfort Plane, measure the perpendicular distance from the headboard to the most inferior tip of the right and left mastoid processes.

13. Tragion Height: With the head in the Frankfort Plane against a board tangential to Vertex and parallel to the Frankfort Plane, measure the perpendicular

distance with an anthropometer from the headboard to right and left Tragion.

14. Tragion Depth: With the head in the Frankfort Plane, measure the perpendicular distance with an anthropometer from the surface on which the back of the head is resting to right and left Tragion.

15. Suprasternale Depth: Measure the perpendicular distance with an anthropometer from the surface on which the body is resting to Suprasternale.

16. Mid-Chest Depth: Measure the perpendicular distance with an anthropometer from the surface on which the body is resting to the point on the anterior surface of the chest mid-way between Suprasternale and Substernale.

17. Substernale Depth: Measure the perpendicular distance with an anthropometer from the surface on which the body is resting to Substernale.

18. Anterior Superior Iliac Spine Depth: Measure the perpendicular distance with an anthropometer from the surface on which the body is resting to the right and left Anterior Superior Iliac Spines.

19. Symphysion Depth: Measure the perpendicular distance with an anthropometer from the surface on which the body is resting to Symphysion.

20. Trochanterion Depth: Measure the perpendicular distance with an anthropometer from the surface on which the body is resting to the right and left Trochanterions.

21. Suprasternale-Acromion Distance: Measure the parallel distance with an anthropometer from Suprasternale to right and left Acromion.

22. Biacromial Diameter: Measure the distance with an anthropometer between the lateral edge of the right and left Acromions.

23. Bideltoid Breadth: Measure the maximum distance with an anthropometer across the deltoid musculature of the upper arm with the elbows held against the body.

24. Chest Breadth at Nipple Level: Measure with an anthropometer the breadth of the chest at the level of the nipples perpendicular to the mid-sagittal plane.

25. Mid-Chest Breadth: Measure with an anthropometer the breadth of the chest at a level mid-way between Suprasternale and Substernale perpendicular to the mid-saqittal plane.

26. Hip Breadth at Iliocristale: Measure with an anthropometer the breadth between the right and left Iliocristale landmarks perpendicular to the mid-sagittal plane.

27. Bispinous Diameter: Measure with an anthropometer the parallel distance between the right and left Anterior Superior Iliac Spines.

28. ASIS-Symphysion Distance: Measure with an anthropometer the parallel distance from Symphysion to right and left Anterior Superior Iliac Spines.

29. Bitrochanteric Breadth: Measure with an anthropometer the distance between right and left Trochanterion perpendicular to the mid-sagittal plane.

30. Acromion-Radiale Length: Measure with an anthropometer the distance between the Acromion and Radiale surface markers parallel to the long axis of the upper limb.

31. Ball of Humerus-Radiale Length: Measure with an anthropometer the distance from the Ball-of-Humerus to Radiale landmarks for both right and left sides. The measurement should be taken parallel to the long axis of the upper limbs.

32. Radiale-Stylion Length: Measure with an anthropometer the distance from the Radiale to Stylion parallel to the long axis of the right and left lower arms.

33. Hand Length: Measure with sliding calipers the length of the hand from the tip of the distal wrist crease to Dactylion parallel to the long axis of the hand.

34. Hand Breadth: Measure with sliding calipers the breadth of the hand between the distal ends of Metacarpal II and Metacarpal V.

35. Hand Depth: Measure with spreading calipers the maximum depth of the hand at the distal end of Metacarpal III.

36. Minimum Wrist Breadth: Measure with sliding calipers the minimum breadth of the wrist just proximal to the radial and ulnar styloid processes.

37. Maximum Forearm Depth: Measure with sliding calipers the maximum forearm breadth at the same level as maximum forearm circumference.

38. Upper Arm Depth: Measure with sliding calipers the depth

of the upper arm at a level midway between the top of the shoulder and the inferior tip of the olecranon process.

39. Femur Length: Measure with an anthropometer the parallel distance from Trochanterion to Fibulare.

40. Fibula Length: Measure with an anthropometer the parallel distance from Fibulare to the lateral Malleolus of the fibula.

41. Tibia Length: Measure with an anthropometer the parallel distance from Tibiale to Sphyrion.

42. Lower Leg Length: Measure with an anthropometer the parallel distance from Tibiale to the most distal point on the heel of the foot.

43. Foot Length: Measure with an anthropometer the length of the right and left feet from the dorsal surface of the heel to the tip of the big toe along an axis parallel to the long axis of the foot.

44. Foot Breadth: Measure with sliding calipers the breadth of the foot at the level of the metatarsal-phalangeal joints along an axis perpendicular to the long axis of the foot.

45. Minimum Ankle Breadth: Measure with sliding calipers the minimum breadth of the ankle proximal to the malleoli.

46. Maximum Calf Depth: Measure with sliding calipers the maximum anterio-posterior depth of the calf at the level of maximum calf circumference.

47. Upper Thigh Breadth: Measure with sliding calipers the breadth

of the upper thigh at the level of the crotch.

48. Head Breadth: Measure with spreading calipers the maximum horizontal breadth on the skull perpendicular to the mid-sagittal plane.

49. Head Length: Measure with spreading calipers the maximum length in the mid-sagittal plane between Glabella and Opisthocranion.

50. Bitragion Diameter: Measure with spreading calipers the distance between right and left Tragions.

51. Bigonial Diameter: Measure with spreading calipers the distance between right and left Gonions.

52. Menton Diagonal Length: Measure with the spreading calipers the greatest distance from Menton to the back of the skull in the mid-sagittal plane.

53. Mastoid-Crinion Length: Measure with the anthropometer the distance from the tip of the mastoid process to crinion parallel to the mid-sagittal plane.

54. Head Circumference: With the tape passing just above Glabella, measure the maximum circumference of the head.

55. Mid-Sagittal Arc Lenght: Place the tape on Glabella and measure the surface arc length in the mid-sagittal plane to Nuchale.

56. Bitragion-Coronal Arc Length: Place the tape on left Tragion and measure the surface arc length to right Tragion perpendicular to the Frankfort Plane.

57. Mid-Neck Circumference: Measure the circumference of the neck with the tape passing inferior, but tangent to, the laryngeal prominence (Adam's Apple).

58. Chest Circumference at Mid-Chest: Measure the horizontal circumference at the level of the point on the anterior surface of the chest midway between Suprasternale and Substernale.

59. Chest Circumference at T12: Measure the horizontal circumference at the level of the Substernale.

60. Hip Circumference, Iliocristale: Measure the horizontal circumference at the level of the Iliocristale landmarks.

61. Buttocks Circumference at Trochanterion: Measure the horizontal circumference at the level of the Trochanterion surface landmarks.

62. Upper Arm Circumference: Measure the circumference of the upper arm at the level of half the length of the upper limb. Measure on a plane perpendicular to the long axis of the upper limbs.

63. Maximum Forearm Circumference: Measure the maximum circumference of the forearm with the tape on a plane perpendicular to the long axis of the limb.

64. Minimum Wrist Circumference: Measure the minimum circumference of the wrist at the level proximal to the styloid processes of the radius and ulna on a plane perpendicular to the long axes of the right and left forearms.

65. Upper Thigh Circumference: Measure the circumference of the thigh tangent to the crotch on a plane parallel to the long axis of the thigh.

66. Maximum Calf Circumference: Measure the maximum circumference of the calf on a plane perpendicular to the long axis of the lower leg. Measure right and left sides.

67. Minimum Ankle Circumference: Measure the minimum circumference of the ankle at the level proximal to the malleoli of the tibia and fibula on a plane perpendicular to the long axis of the lower leg.

C. List of Landmark Definitions

ACROMION The most lateral projection on the superior edge of the acromial process of the scapula.

ANTERIOR SUPERIOR ILIAC SPINE A point on the pelvis located at the most anterior projection of the superior spine on the iliac portion of the pelvis.

BALL OF HUMERUS The level of the most superior portion of the bicipital groove lying between the greater and lesser tuberosities of the humerus.

CRINION The midpoint of the hairline on the forehead.

DACTYLION The most distal point on the tip of the middle digit (III).

DISTAL Remote; farther from any point of reference; opposed to proximal.

FIBULARE The most proximal point on the head of the fibula.

GLABELLA The most anterior point on the forehead that lies between the brow ridges in the mid-sagittal plane.

GONION The last lateral point at the intersection of the horizontal and ascending rami of the mandible.

ILIOCRISTALE The most superior point on the lateral edge of the iliac crest of the pelvis.

MALLEOLUS The most medial and lateral projections on the distal end of the tibia and fibula, respectively.

MANUBRIUM The cranial portion of the sternum, which articulates with the clavicles and the first two pairs of ribs.

MASTOID The most inferior point on the tip of the mastoid process of the skull.

MENTON The most antero-inferior point on the chin in the mid-sagittal plane.

METACARPALS The long bones in the palm of the hand which articulate with the phalanges of the fingers.

NUCHALE The point on the back of the skull in the mid-sagittal plane defined by the superior margin of the occiput and the neck, or nuchal, musculature.

OLECRANON PROCESS The proximal portion of the ulna which forms the bony projection in the posterior projection of the elbow.

OPISTHOCRANION The point on the back of the skull which lies at the greatest distance from Glabella.

PROXIMAL Nearest; closer to any point of reference; opposed to distal.

RADIALE The most superior lateral projection of the head of the radius found superficially at the level of the elbow dimple.

SPHYRION The most distal tip of the tibia on the medial side of the ankle.

STYLION The most distal tip of the radial styloid process.

SUBSTERNALE A point on the anterior surface of the chest at the most inferior tip of the xiphoid process of the sternum.

SUPRASTERNALE A point on the most inferior margin of the sternal notch at the top of the manubrium.

SYMPHYSION A point in the mid-sagittal plane on the most anterior superior edge of the pubic symphysis of the pelvis.

TIBIALE The point on the proximal end of the tibia located as the highest point on the margin of the glenoid in an antero-medial direction near the knee joint.

TRAGION The notch in the cartilage of the ear at the superior margin of the tragus.

TROCHANTERION The most superior projection of the Greater Trochanter of the femur.

VERTEX The most superior point in the mid-sagittal plane on the head.